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(54) **SIMULTANEOUS SWITCHING NOISE FILTER ARCHITECTURE AND METHOD**

(75) Inventors: **Yee Huan Yew**, Bayan Lepas (MY); **Hong Shi**, Santa Rosa, CA (US)

(73) Assignee: **Altera Corporation**, San Jose, CA (US)

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(51) **Int. Cl.**
H01P 1/203 (2006.01)
H03H 7/09 (2006.01)

(52) **U.S. Cl.** **333/204**; 333/185

(58) **Field of Classification Search** 333/33, 333/34, 166–168, 175, 176, 185, 202–205, 333/246
See application file for complete search history.

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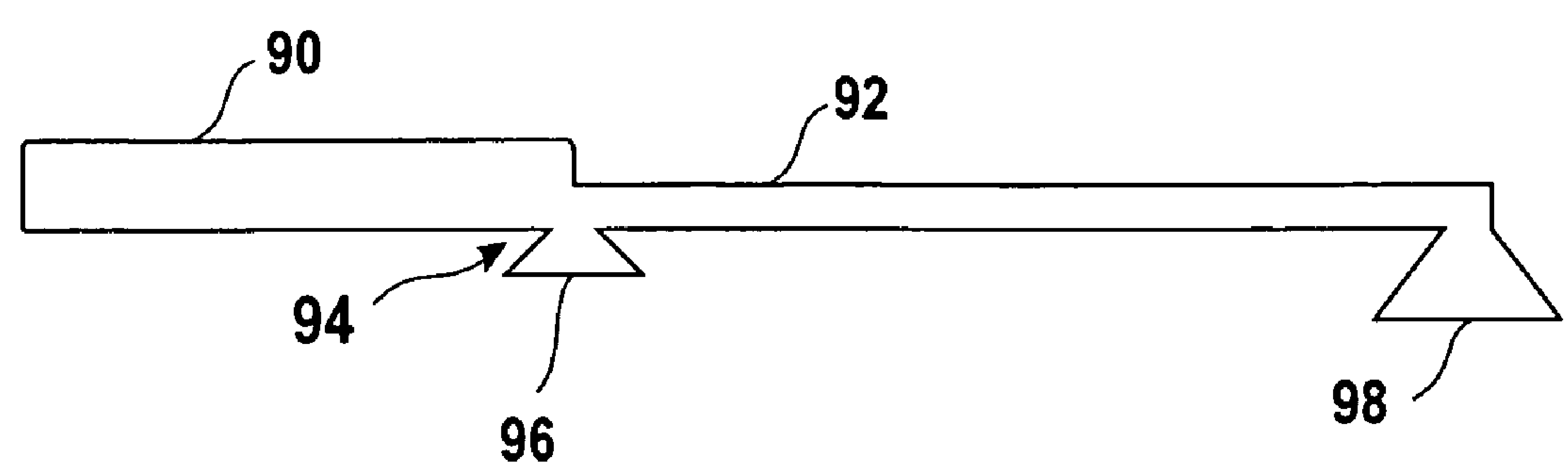
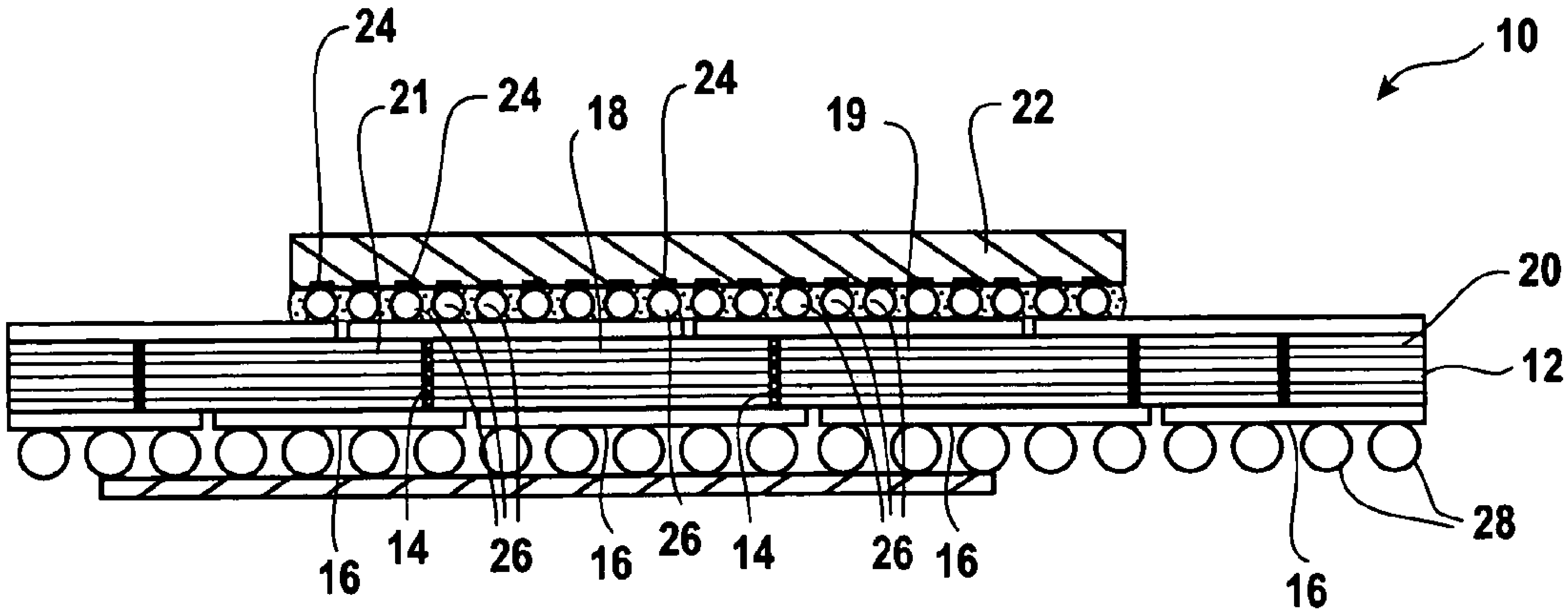
Primary Examiner — Benny Lee
Assistant Examiner — Gerald Stevens
(74) *Attorney, Agent, or Firm* — Martine Penilla & Gencarella, LLP

(57) **ABSTRACT**

The present invention is directed to a transmission line assembly and method of propagating signals therethrough that features forming transmission lines of the assembly to provide desired filtering properties. To that end, the assembly includes a plurality of spaced-apart transmission lines placing first and second sets of active circuits in electrical communication, with a subset of the plurality of spaced apart transmission lines having dimensions to filter unwanted characteristics of signals, propagating between the first and second sets and inductively coupled between one or more of the plurality of spaced-apart transmission lines. The method performs the function of the assembly.

18 Claims, 4 Drawing Sheets

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24
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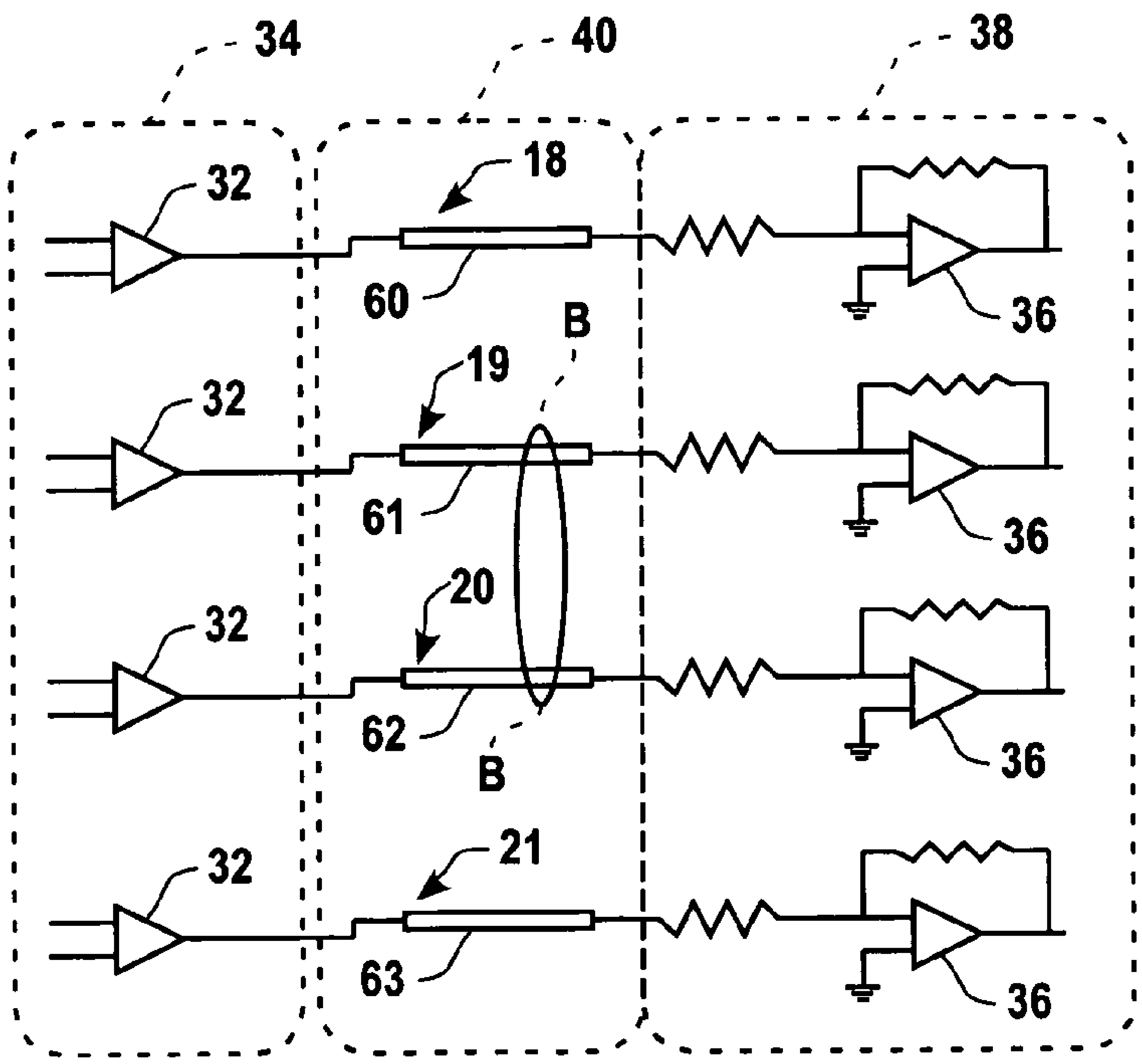
16

FIG. 1


34
40
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32
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B
61
36
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B
36
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63
36

FIG. 2

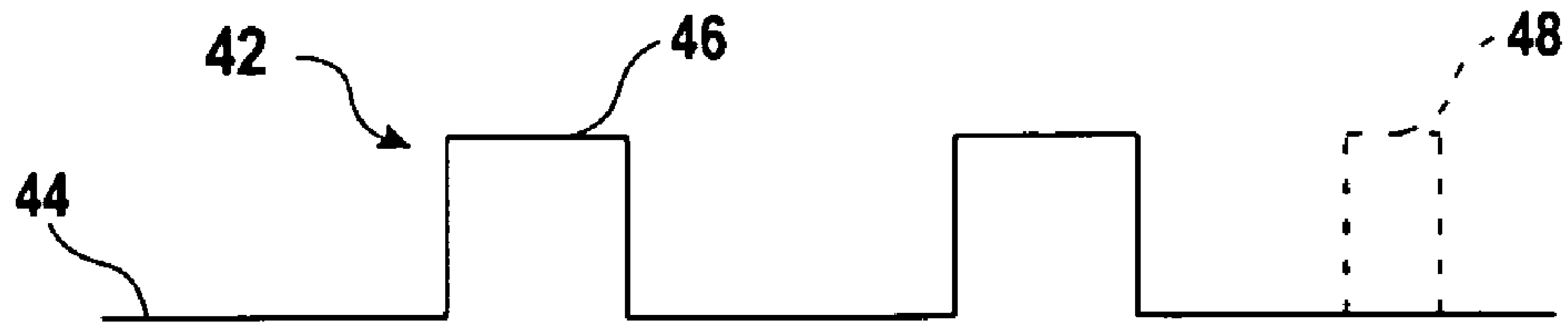

FIG. 3

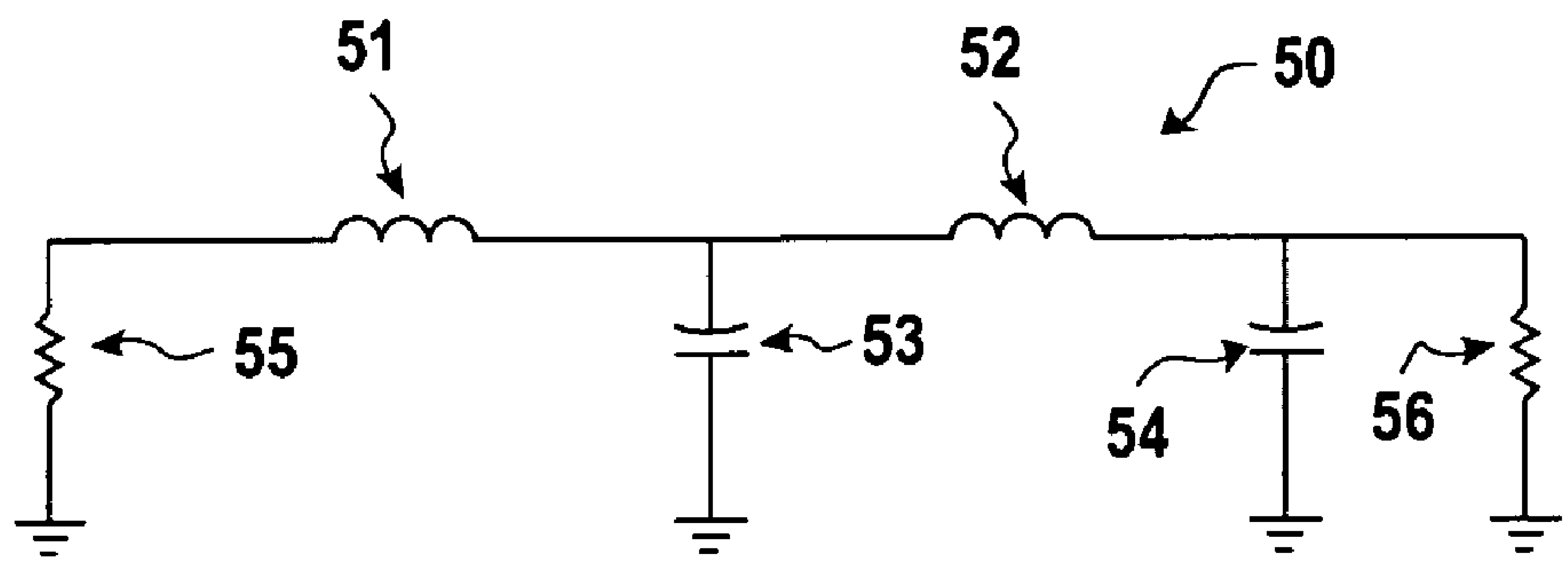

FIG. 4

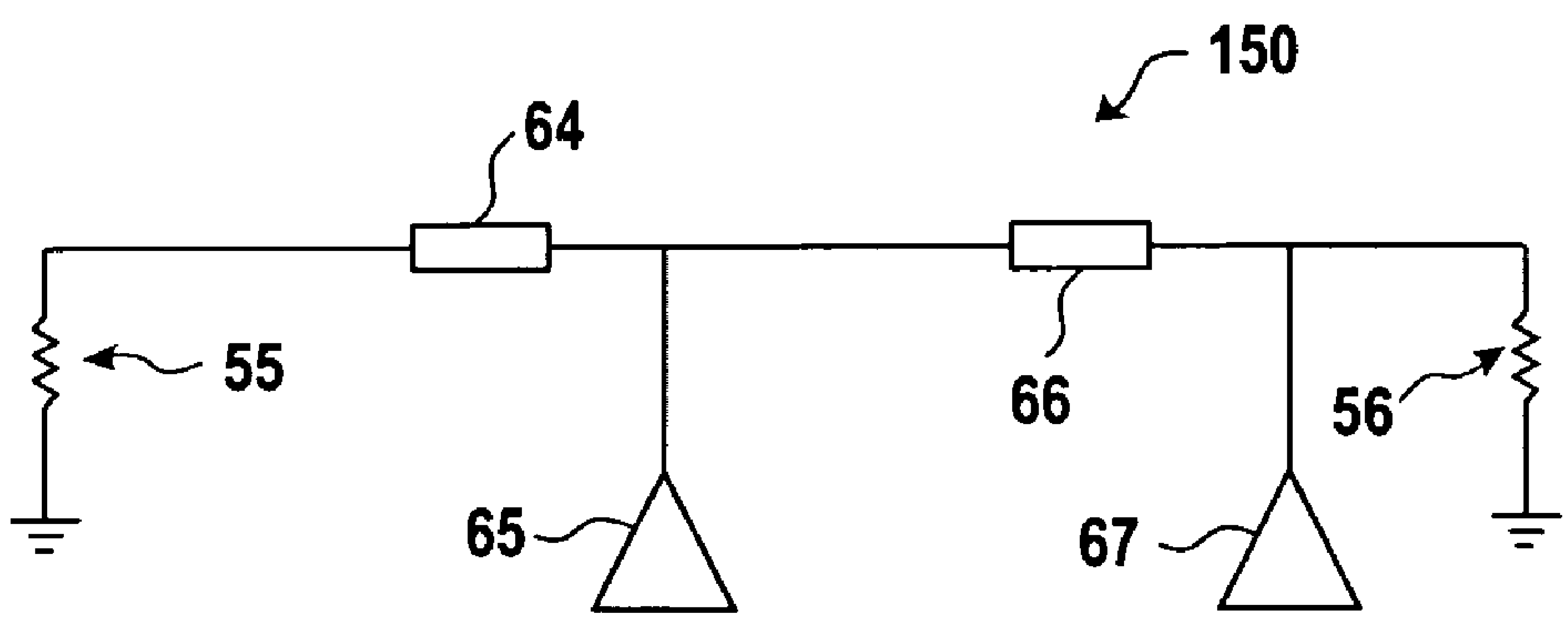

FIG. 5

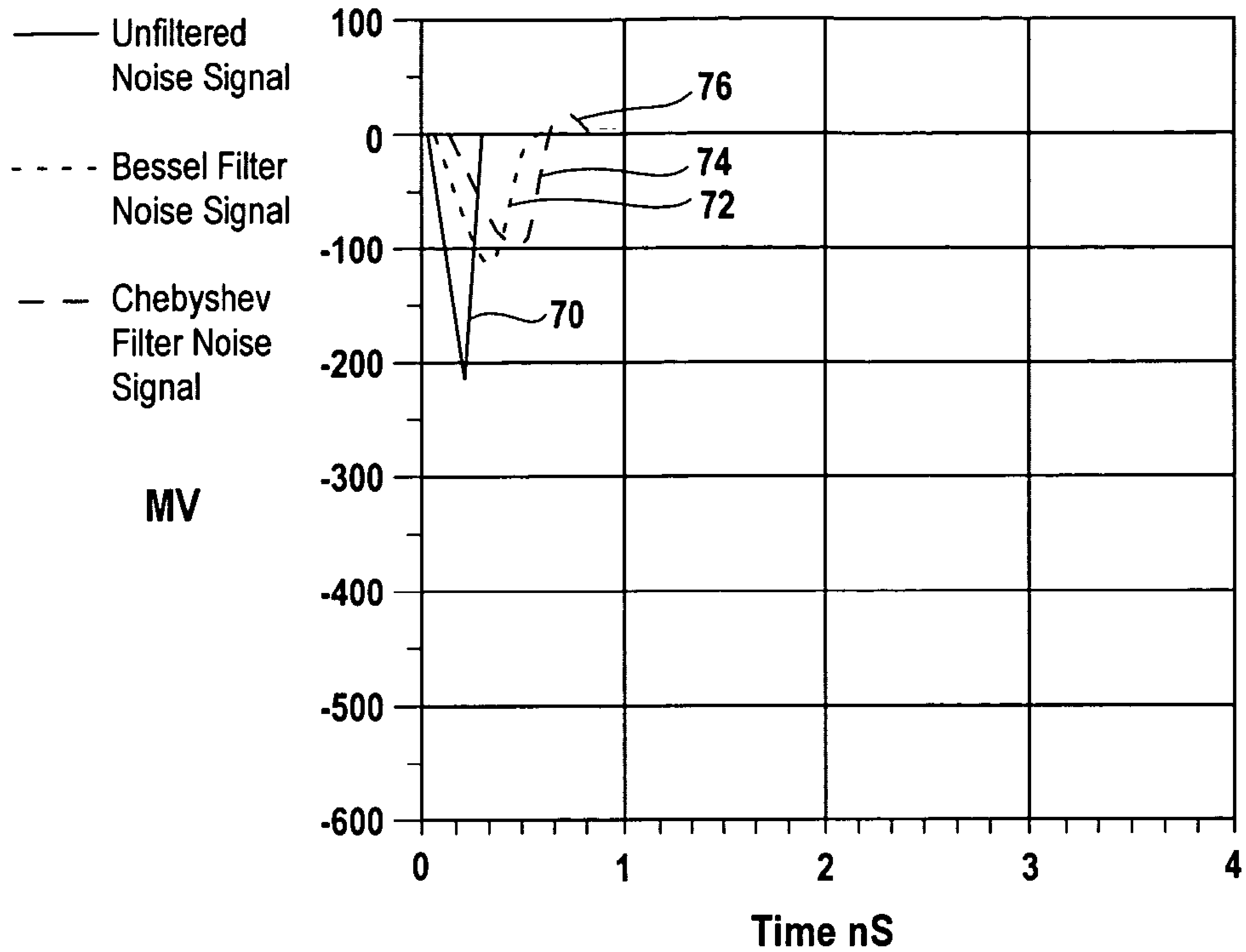
Unfiltered
Noise Signal
Bessel Filter
Noise Signal
Chebyshev
Filter Noise
Signal
MV
100
0
-100
-200
-300
-400
-500
-600
76
74
72
70
0
1
2
3
4
Time nS

FIG. 6

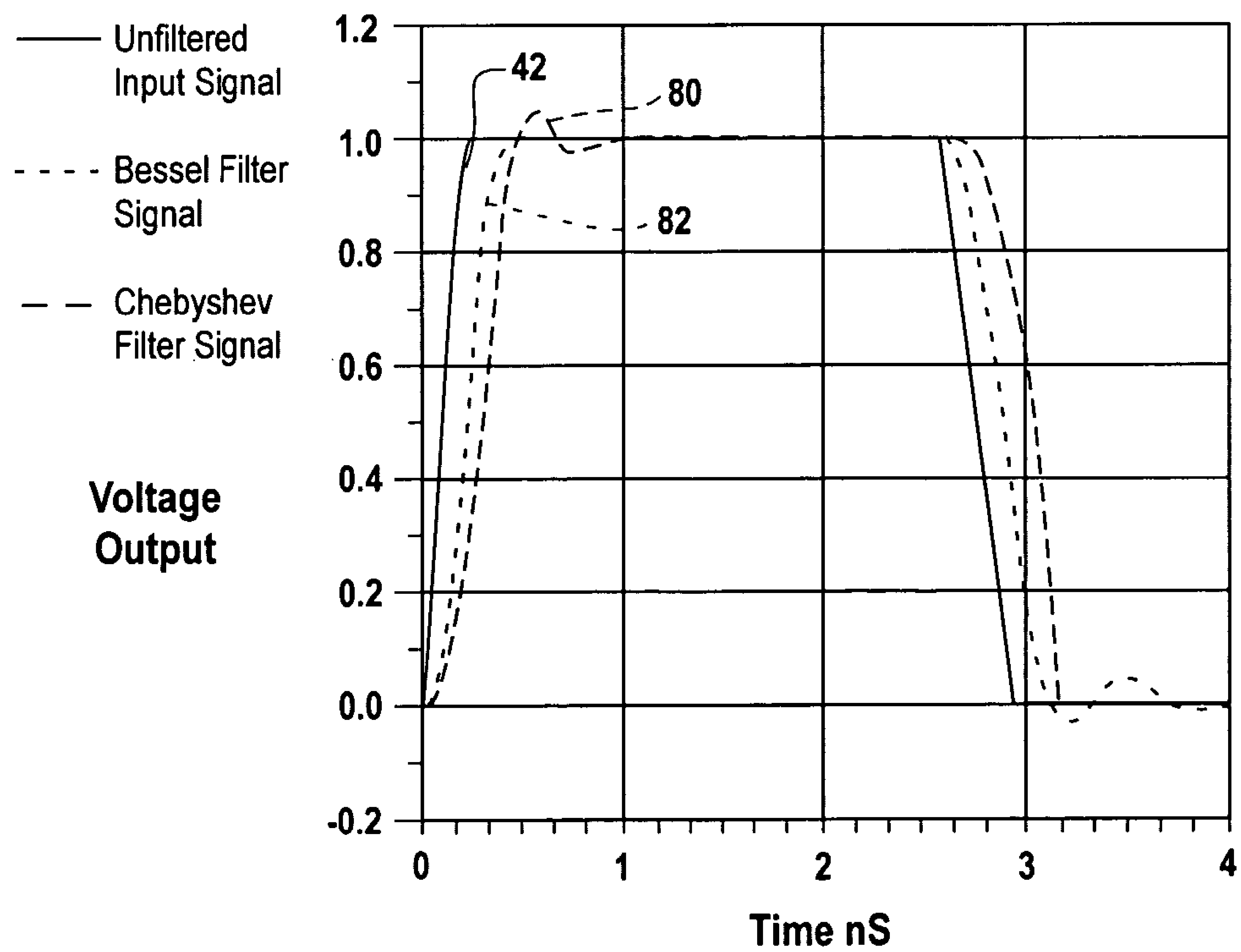
Unfiltered
Input Signal
Bessel Filter
Signal
Chebyshev
Filter Signal
Voltage
Output
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
42
80
82
0
1
2
3
4
Time nS

FIG. 7

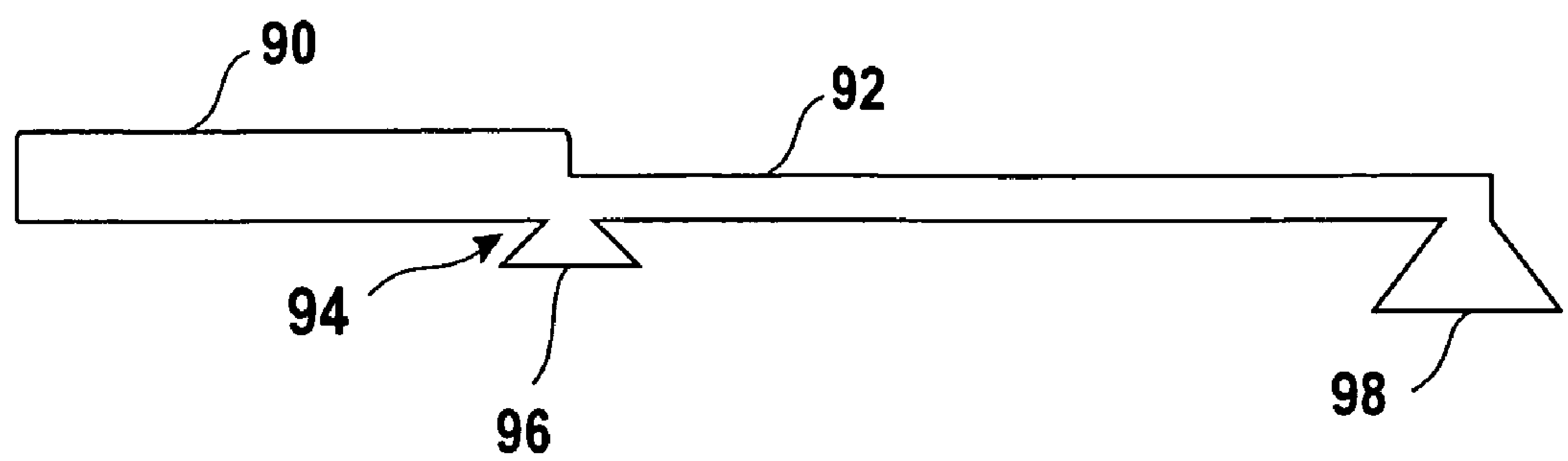

FIG. 8

SIMULTANEOUS SWITCHING NOISE FILTER ARCHITECTURE AND METHOD

CROSS REFERENCE TO RELATED APPLICATIONS

This application claims priority from U.S. Provisional Patent Application No. 60/970,220, filed Sep. 5, 2007, and entitled "SIMULTANEOUS SWITCHING NOISE FILTER ARCHITECTURE AND METHOD." This provisional application is herein incorporated by reference.

BACKGROUND

The present invention relates to integrated circuit systems and more particularly to filtering techniques to reduce simultaneous switching noise between transmission lines disposed in printed circuit boards (PCBs) and placing integrated circuits in signal communication, referred to as integrated circuit assemblies (ICAs).

During normal operations of the ICAs, close proximity of transmission lines cause inductively coupling of signals between adjacent transmission lines in the presence of a time varying current in one of the same. Inductively coupling of signals, in this manner, is typically referred to simultaneous switching noise (SSN). SSN may interfere with operation of the integrated circuit resulting in faulty operation of the same. As a result, there have been several attempts to reduce switching noise.

An existing technique to reduce SSN employs multiple low-inductance bypass, or decoupling, capacitors. Decoupling capacitors filter noise by "short circuiting" high frequency components of a noise signal and are often connected between each power plane and adjacent ground plane. However, the inclusion of additional components, such as capacitors, results in increased cost of production of ICAs.

A need exist, therefore, to provide improved ICAs manufacturing techniques.

SUMMARY

It should be appreciated that the present invention can be implemented in numerous ways, such as a process and a package. Several inventive embodiments of the present invention are described below.

The present invention is directed to an integrated circuit assembly and method of propagating signals therethrough that features forming transmission lines of the assembly to provide desired filtering characteristics. To that end, the integrated circuit assembly includes first and second sets of active circuits and a plurality of spaced-apart transmission lines placing the first and second set of active circuits in electrical communication. A subset of the plurality of spaced apart transmission lines have dimensions to filter unwanted characteristics of signals propagating between the first and second sets and inductively coupled to one or more of the plurality of spaced-apart transmission lines. An integrated circuit having spaced apart transmission lines with dimensions to filter unwanted characteristics of signals propagating between the first and second sets is provided in another aspect of the invention.

These and other aspects of the invention will become apparent from the following detailed description, taken in conjunction with the accompanying drawings, illustrating by way of example the principles of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention can be best understood by reference to the following description taken in conjunction with the accompanying figures, in which like parts may be referred with like numerals.

FIG. **1** is a simplified cross-sectional view of an integrated circuit system in accordance with one embodiment of the present invention;

FIG. **2** is a schematic of a portion of the integrated circuit system, shown in FIG. **1**, coupled to loads in accordance with the present invention;

FIG. **3** is simplified graph showing signal propagation along one of the channels shown in FIG. **1**;

FIG. **4** is a simplified electrical schematic showing a basic filter configuration in accordance with the present invention;

FIG. **5** is a simplified schematic showing the implementation of the electrical functions shown in the electrical schematic of FIG. **4**;

FIG. **6** is a graph comparing the signal noise generated by inductively coupling between transmission lines shown in FIG. **2**;

FIG. **7** is a graph comparing the signal output from one of the transmission lines mentioned in FIG. **6**;

FIG. **8** is a simplified plan view showing the dimension of the transmission lines shown in FIG. **1** to implement the filter shown in FIG. **4**, in accordance with the present invention.

DETAILED DESCRIPTION OF THE INVENTION

Referring to FIG. **1**, an integrated circuit system **10** is shown as including a substrate **12**, typically a printed circuit board (PCB) having a plurality of vias **14** and a plurality of conductive transmission lines **18**, **19**, **20** and **21** disposed upon one side thereof in electrical communication with one or more of vias **14**. A plurality of contact pads **16** is disposed on a side of substrate **12** that is opposite to the side upon which conductive transmission lines **18**, **19**, **20** and **21** are disposed and in electrical communication with one or more of vias **14**. Vias **14** place conductive transmission lines **18**, **19**, **20** and **21** in electrical communication with different subsets of output contact pads **16**. Integrated circuit **22** includes a plurality of bonding pads **24** and is mechanically and electrically coupled to substrate **12** by solder bumps **26** disposed between bonding pads **24** and conductive transmission lines **18**, **19**, **20** and **21**, using techniques well known in the art, discussed further below. Signals from integrated circuit **22** are transmitted outside of integrated circuit package **10** by solder bumps **28** that are attached to and in electrical communication with contact pads **16**. Solder bumps **28** are also used to place other circuits, such as integrated circuit **30**, in electrical communication with integrated circuit **22**.

Referring to both FIGS. **1** and **2**, typically integrated circuit **22** includes a plurality of active circuits **32** defining a first set **34**. Integrated circuit **30** includes a plurality of active circuits **36**, defining a second set **38**. First and second sets **34** and **38** are in electrical communication via a set **40** of transmission lines **18**, **19**, **20** and **21**.

Referring to both FIGS. **2** and **3**, signals, such as signal **42** propagate between first and second seconds **34** and **38** over set **40** of conductive transmission lines **18**, **19**, **20** and **21**. As is well known, the physical proximity of adjacent conductive transmission lines **18**, **19**, **20** and **21** may attribute to cross-coupling of signals propagating between first and second sets **34** and **38**. The cross-coupling results from a change in current flow through one of conductive transmission lines **18**, **19**, **20** and **21** that occurs as a result of a transition of signal **42** from a logical zero “0” voltage level **44** to a logical “1” voltage level **46**. This produces a magnetic field, B, that is shared between one or more adjacent conductive transmission lines **18**, **19**, **20** and **21** inductively coupling a signal by inducing current flow, referred to as cross-talk or simultaneous switching noise (SSN). SSN presents as an inductively coupled signal **48** on the conductive transmission lines **18**, **19**, and **21** in which the induced current is present. As the magnitude of inductively coupled signal **48** approaches voltage level **44**, active circuit **36** receiving the same may incorrectly identify the same as signal **42**. This may be deleterious to the operation of active circuit **36**.

Referring to FIGS. **2**, **3** and **4**, one manner in which to attenuate the characteristics of inductively coupled signal **48** is to provide an RLC filter **50** that includes inductive components **51** and **52**, capacitive components **53** and **54** and resistive components **55** and **56**. Inductive components **51** and **52** are connected in series and capacitive components **53** and **54** are connected in parallel between ground and opposed side of inductive component **52**. Resistive component **55** is coupled in parallel with capacitive component **53** between ground and opposed sides of inductive component **51**, and resistive component **56** is coupled in parallel with capacitive component **54** between ground and a common side of inductive component **52**.

To avoid the increased cost associated with including inductive components **51** and **52** and capacitive components **53** and **54** to assembly **10**, filter **50** is implemented in assembly **10** by establishing dimensions of conductive transmission lines **18**, **19**, **20** and **21** to provide desired filtering properties. To that end, each of conductive transmission lines **18**, **19**, **20** and **21** includes filter segments **60**, **61**, **62** and **63** that provide the aforementioned filter properties to form a transmission line filter **150**, shown in FIG. **5**. Transmission line filter **150** includes resistive components **55** and **56** that correspond to the resistance presented by active circuits **32** and **36**, respectively, at opposed ends of conductive transmission lines **18**, **19**, **20** and **21**. Inductive components **51** and **52**, as well as, capacitive components **53** and **54** have been replaced appropriate dimensions of material from which filter segments **60-63** of conductive transmission lines **18**, **19**, **20** and **21** are formed, shown as **64**, **65**, **66** and **67**.

The dimensions of segments **60-63** of conductive transmission lines **18**, **19**, **20** and **21** are configured to provide desired filtering properties. The filtering properties are a function of a coupling component [M], which represents inductively coupling characteristics of adjacent conductive transmission lines **18**, **19**, **20** and **21** in the presence of a time varying current di/dt associated with signal **42** on one of conductive transmission lines **18**, **19**, **20** and **21**. Specifically, a magnitude of inductive coupled signal **48** V on one of conductive transmission lines **18**, **19**, **20** and **21** may be expressed as follows:

$$V_m=[M_n]di/dt$$

where V_m is the transmission line upon which signal **48** is present and M_n is the coupling component between the conductive transmission lines **18**, **19**, **20** and **21** upon which signal **42** and the conductive transmission lines **18**, **19**, **20** and **21** upon which inductively coupled signal **48** is present. Time varying current di/dt is the change of current present when signal **42** alternates between a logic “0” voltage level **44** and a logic “1” voltage level **46** and vice-versa.

Referring to FIGS. **2**, **6** and **7**, it was determined that many different filtering properties may be employed. For example, dimensions of filtering segments **60-63** may be established to provide a Chebyshev filter, a Bessel filter and the like. As shown, a magnitude of an unfiltered inductive coupled signal is shown by curve **70** to be in excess of 200 millivolts. Implementation of Bessel filtering properties in segments **60-63** results in a reduction of noise to a little greater than less than 100 millivolts, shown by curve **72**. Implementation of Chebyshev filtering properties in segments **60-63** results in a further reduction of noise to less than 100 millivolts. However, Chebyshev filtering properties results in a distortion **76**. This results from the sharp cutoff frequency response of Chebyshev filters. Distortion **76** feeds back to the transmission line and therefore, the signal **42** propagating thereon that produces the SSN represented by curve **74**, as shown by signal **80**, with a curve **82** representing output from the same transmission line having Bessel filtering properties. As a result, it is desired to provide segments **60-62** with dimensions to provide Bessel filtering properties. For example, it is desired that filtering properties attenuate a bandwidth of inductively coupled signal **48**, as measured in the frequency domain, while maintaining the magnitude to be below a threshold voltage associated with the active circuits **36**.

In the present example, the threshold voltage is defined as the voltage at which point field effect transistors (not shown) within active circuits **36** begin to operate, e.g., “turn-on”. It should be noted that the filtering properties are, therefore, determined based upon the active circuits **36**, the parameters of signal **42**, the materials from which segments are formed and the parasitic characteristics of coupling active circuits **32** and **36** to set **40** of conductive transmission lines **18**, **19**, **20** and **21**.

Referring to FIG. **8**, to that end, one example of segments **60-63** includes providing a copper trace **90** have a length of approximately 762 micrometers, a width of approximately 40 micrometers and a thickness of approximately 17 micrometers. Extending from trace **90** is a trace **92** with a length of approximately 18 micrometers, a width of approximately 20 micrometers and a thickness of approximately 17 micrometers. Extending from a junction **94** of traces **90** and **92** is a triangular portion **96**, the sides of which have a common length, e.g., 50 micrometers. Disposed proximate to a terminus of trace **92**, positioned opposite to junction **94** is a second triangular portion **98**, the sides of which have a common length, e.g., 100 micrometers. In one embodiment, the angle of the sides of the triangular portions **96** and **98** with the bottom of traces **90** and **92** is about 60 degrees. It is possible to form the features **90**, **92**, **94**, **96** and **98** to have larger sizes, e.g., when formed on a PCB; however, it is desired that the aforementioned ratios of dimensions be substantially maintained. Additionally, it is possible to fabricate vias **14** to provide the function provided by features **92**, **94**, **96** and **98**, in lieu of conductive transmission lines **18**, **19**, **20** and **21** or, alternatively, in conjunction therewith. Thus, the traces can be implemented in a horizontal and vertical direction.

Although the foregoing invention has been described in some detail for purposes of clarity of understanding, it will be apparent that certain changes and modifications may be practiced within the scope of the appended claims. Accordingly, the present embodiments described above are to be considered as illustrative and not restrictive, and the invention is not to be limited to the details given herein, but may defined by the appended claims, including full scope of equivalents thereof.

What is claimed is:

1. A transmission line assembly comprising:

a plurality of spaced-apart electrically conductive traces on a substrate, with a subset of the plurality of spaced apart electrically conductive traces having dimensions to filter unwanted characteristics of signals propagating through the electrically conductive traces and inductively coupled between one or more of the plurality of spaced-apart electrically conductive traces, the signals propagating though the electrically conductive traces defining inductively coupled signals, wherein the electrically conductive traces of the subset are configured as a first copper trace joined to a second copper trace through a triangular copper portion and wherein the first copper trace is wider than the second copper trace.

2. The transmission line assembly as recited in claim **1** wherein the dimensions of the electrically conductive traces of the subset are configured to function as one of a Bessel filter or a Chebyshev filter.

3. The transmission line assembly as recited in claim **1** wherein the substrate is a printed circuit board and wherein the second copper trace has another triangular copper portion attached to a terminus of the second copper trace.

4. The transmission line assembly as recited in claim **1** wherein the dimensions of the electrically conductive traces of the subset are configured to provide filtering properties, with the filtering properties being a function of a coupling component representing inductively coupling characteristics of the inductively coupled signals and a time varying current of the inductively coupled signals when alternating between voltage levels associated with a logical "1" and a logical "0".

5. The transmission line assembly as recited in claim **1** wherein the dimensions of the electrically conductive traces of the subset are configured to provide filtering properties, with the filtering properties including a reduction in a bandwidth of the inductively coupled signals.

6. The transmission line assembly as recited in claim **1** wherein the dimensions of the electrically conductive traces of the subset are configured to provide filtering properties, with the filtering properties including a reduction in a bandwidth and magnitude of the inductively coupled signals.

7. The transmission line assembly as recited in claim **1** wherein the dimensions of the electrically conductive traces of the subset are configured to provide filtering properties, with the filtering properties including a reduction in a magnitude of the inductively coupled signals to be less than a voltage threshold associated with integrated circuits coupled to the electrically conductive traces.

8. The transmission line assembly as recited in claim **1** wherein the dimensions of the electrically conductive traces of the subset are configured to provide filtering properties, with the filtering properties including a reduction in a bandwidth and magnitude of the inductively coupled signals, with the magnitude being less than a voltage threshold associated with integrated circuits coupled to the electrically conductive traces.

9. A transmission line assembly comprising:

a plurality of spaced-apart electrically conductive traces on a substrate, with a subset of the plurality of spaced apart electrically conductive traces having dimensions to function as a Bessel filter and attenuate unwanted characteristics of signals propagating through the electrically conductive traces and inductively coupled between two or more of the plurality of spaced-apart electrically conductive traces, wherein at least one of the electrically conductive traces are configured as a first copper trace joined to a second copper trace through a triangular copper portion and wherein the first copper trace is wider than the second copper trace.

10. The transmission line assembly as recited in claim **9** wherein the substrate is disposed on a printed circuit board.

11. The transmission line assembly as recited in claim **9** wherein the unwanted characteristics includes a bandwidth of the inductively coupled signals.

12. The transmission line assembly as recited in claim **9** wherein the unwanted characteristics includes a bandwidth and magnitude of the inductively coupled signals.

13. The transmission line assembly as recited in claim **9** wherein the unwanted characteristics includes a bandwidth and a magnitude of the inductively coupled signals, with the magnitude being less than a voltage threshold associated with integrated circuits coupled to the electrically conductive traces.

14. The transmission line assembly as recited in claim **13** wherein the dimensions of the electrically conductive traces of the subset are configured to provide filtering properties, with the filtering properties being a function of a coupling component representing inductive coupling characteristics of the inductively coupled signals and a time varying current of the inductively coupled signals when alternating between voltage levels associated with a logical "1" and a logical "0".

15. A method of filtering signals propagating through a plurality of spaced-apart electrically conductive traces on a substrate and inductively coupled between two or more of the plurality of spaced-apart electrically conductive traces, the method comprising:

forming the electrically conductive traces with dimensions to provide desired filtering properties and attenuate unwanted characteristics of the inductively coupled signals, the forming further including providing the electrically conductive traces wherein at least one of the electrically conductive traces are configured as a first copper trace joined to a second copper trace through a triangular copper portion and wherein the first copper trace is wider than the second copper trace.

16. The method as recited in claim **15** wherein the forming further includes providing the electrically conductive traces with properties of one of a Bessel filter or a Chebyshev filter.

17. The method as recited in claim **15** wherein the unwanted characteristics include a frequency bandwidth and a magnitude of the inductively coupled signals.

18. The method as recited in claim **17** wherein of the inductively coupled signals is attenuated the magnitude to be less than a voltage threshold associated with integrated circuits coupled to the electrically conductive traces.

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